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Interplant competition among oat and barley varieties and isolines

by

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INTRODUCTION

Recently, Murphy et al. (1982) reported that the isoline composition of a multiline variety of oats did not remain constant over a four-year period that the multiline was propagated. The composition changed similarly and significantly when the multiline was grown in a rust-free and in a rust-epidemic environment, so the authors concluded that the isolines possessed differing competitive abilities that might be related to expression of certain agronomic trait(s). As a follow-up to this study, I conducted experiments (a) to determine whether differing competitive abilities could be measured among the isolines used in the Murphy et al. (1982) study, among oat isolines in the Multiline E series (Frey and Browning, 1976b), among five oat varieties, and among oat and barley varieties and (b) to assess whether specific agronomic traits could be associated with differences in competitive ability.

LITERATURE REVIEW

Competitive Ability

Competitive ability as applied to plants is defined as a genotype's ability to yield well and successfully compete for soil water and nutrients when surrounded by similar or dissimilar genotypes (Francis, 1981). Good correspondence between high yields in pure stand and good competitive ability in mixtures has been reported for barley (*Hordeum vulgare* L.) (Allard and Adams, 1969; Harlan and Martini, 1938), wheat (*Triticum aestivum* L.) (Allard and Adams, 1969; Jensen and Federer, 1965), and maize (*Zea mays* L.) (Kannenberg and Hunter, 1972). Also, a negative relationship between yield in pure stand and competitive ability in mixture was reported for barley (Wiebe et al., 1963) and rice (*Oryza sativa* L.) (Jennings and de Jesus, Jr., 1968). Donald (1968) suggested that a weak competitor in mixtures makes a minimum resource demand per unit dry matter produced, and thus produces efficiently and well in pure stand.

In breeding populations that are heterogeneous, natural selection may favor preferential survival of genotypes that are inherently higher yielding, as well as competitive (Kannenberg and Hunter, 1972; Khalifa and Qualset, 1974). Therefore, genotypic frequencies will affect productivity of a population.

Competitive abilities and selective values of genotypes appear to be influenced strongly by environments in which they are grown. In the field, plants in a population interact by competing for available resources, which affects the yield of the crop (Donald, 1963; Wegrzyn et al., 1980). Eddowes (1969) found that competition among maize plants at vegetative stage was postponed by application of nitrogen and maintenance of soil moisture near field capacity. The amount of available nitrogen was a critical factor in determining the interactive effect of nitrogen and light on grain yield. The supply of either factor affected the capacity of the crop to utilize the other, but ultimately, light became dominant. Donald (1958) found that when _Lolium_ and _Phalaris_ species competed only for soil nutrients, the prime effect was reduced nutrient availability for the weaker competitor. Limited nutrients reduced foliar development and the plant's capacity to utilize light. From experiments in which Atlas and Vaughn barley varieties were grown in pure and mixed stands under full daylight and several levels of shading, Edwards and Allard (1963) concluded that competition between these varieties was not associated with limited light. Watson et al. (1958) found that differential grain yields of barley varieties were due to photosynthesis levels in the spikes.

Environmental conditions affect the potential yields of plants grown in homogeneous and heterogeneous stands, also.

Frey and Maldonado (1967) showed that heterogeneous oat (*Avena sativa* L.) varieties had a 4% yield advantage over homogeneous ones when the environment was suboptimal due to late planting. They conjectured that oat plants in a mixture that were not damaged by heat stress increased their productivities by utilizing nutrients and moisture that heat damaged plants could not utilize. Hartman and Allard (1964) concluded that competition between Atlas and Vaughn barley plants was primarily for moisture, but intensity of competition at any moisture level depended on nutrient availability. In a study by Snaydon (1971), ladino clover (*Trifolium repens* L.) populations that evolved on acid soil yielded 47% more on acid than on calcareous soil, and populations that evolved on calcareous soil yielded 44% more on calcareous than on acid soil.

Schutz and Brim (1967) defined four types of intergenotypic competition: undercompensation, complementary compensation, neutral or no compensation, and overcompensation. Neutral compensation occurs when components do not compete with each other, and the mixture yield is equal to the mean of the components grown in pure stand. Undercompensation occurs when the increase in yield of the better competitor is less than the decrease in the poor competitor. Complementary compensation occurs when the increase in yield of one component is equal to the decrease in the other component. Overcompensation occurs when the increase in yield of one component exceeds the decrease of the other component.

Complementary compensation has been reported for maize (Eberhart et al., 1964) and barley (Early and Qualset, 1971; Smith and Lambert, 1968). According to Schutz and Brim (1971), overcompensation in heterogeneous soybean (*Glycine max* (L.) Merr.) populations was essential for a high degree of yield stability. Roy (1960) sowed two rice varieties in alternate rows and found that overcompensation with the planting pattern gave a yield that was 126% of the mean for the varieties grown separately.

Theories for Competitive Ability

Research to determine a genotype's competitive ability has concentrated on differentials for agronomic characters. For example, Lee (1960) determined that the competitiveness of Atlas vs Vaughn barley was due to the differential tiller production and survival of the two varieties. By jointing and booting stages, the number of tillers showed advantage and disadvantage for Vaughn and Atlas, respectively. At booting, Vaughn still had more tillers than Atlas in mixed stand, but by anthesis, the trend reversed; and at maturity, Atlas accounted for 55% of the spikes in the mixture. Lee suggested that the competitive advantage of Atlas was a developmental process that occurred over time.

Sakai and his colleagues (Sakai, 1955, 1956; Sakai and

Suzuki, 1955a,b) have shown that newly created autopolyploids have poor competitive ability, whereas natural allopolyploids are good competitors. In fact, Sakai and Suzuki (1955a) showed that barley autotetraploids were inferior in competitive ability to the diploids used to create them. Autotetraploids were less vigorous and produced fewer seed than diploids when the two were grown in a mixed stand.

Studies with rice (Akita, 1978, 1982a,b,c) and wheat (Chapman et al., 1969; Nerson, 1980; Puckridge and Donald, 1967) investigated the influence of plant densities on competition. With rice, yield was fairly constant for many planting densities, whereas yield of wheat was linearly and positively correlated with planting density. Yield components, especially tillering, of rice increased to compensate for low planting density, and for wheat they did not.

An important factor in competition between buckwheat Fagpyrum esculentum L.) and green gram (Phaseolus viridissimus L.) plants was plant height (Iwaki, 1959). Stem elongation of buckwheat was twice that of green gram which enabled buckwheat to shade green gram plants. Competition studies in rice (Gomosta and Haque, 1979; Jennings and de Jesus, Jr., 1968; Raju and Varma, 1979; Sano and Yamahishi, 1976) showed that vigorous, tillering, tall, leafy genotypes were more competitive in mixtures than were short, erect, sturdy plant types. Jennings and Aquino (1968) found tiller and leaf number, leaf length, spreading growth habit, leaf area, dry weight, and height were greater in strong competitors. Characters that increased size and vegetative vigor in early growth stages conferred strong competitive ability. Oka (1960) found no correlation between competitive ability and agronomic characters in rice, and he said that competitive ability was genetically controlled.

Jensen and Federer (1964) found that alternately sown rows of tall and short wheat genotypes enhanced yield, and Fonseca and Patterson (1968) found five yield component traits that enhanced wheat yield. Busch and Luizzi (1979) found no intergenotypic competition for plant height, days to heading, and grain yield between tall and semidwarf wheats. Different factors may be responsible for grain yield and competitive ability of barley since no evidence has been found that competitive ability is associated with yielding ability (Rasmusson and Cannell, 1970; Sakai and Gotoh, 1955).

Measurement of Competitive Ability

Randomized complete-block (Puckridge and Donald, 1967), diallel (Whitehouse et al., 1958), split-plot, and hexagon plant arrangements have been used to measure competitive ability and yield performance of pure line varieties and mixtures. Sakai (1955) used a hexagon arrangement to measure a genotype's competitive ability. Plants of one genotype were sown in the center of each of two paired hexagon plots. The center plant was surrounded by six plants of its own genotype (X^A) in one plot and by six plants of another genotype (X^N) in the adjacent plot. The ratio yields of X^N/X^A is a measure of the plant's competitive ability. Another pattern, shown below, has been used to measure competitive ability of wheat (Allard and Adams, 1969; Veevers, 1978) and soybeans (Schutz and Brim, 1967):

Y*	Y	Y*
Y	X	Y
Y*	Y	Y*

where X is the test genotype, Y is the inner ring and Y* is the outer ring of competitor genotypes. X, Y, and Y* may be single plants or hills sown with more than one plant in each. Donald (1958) and Snaydon (1971) measured competition by growing populations in pots (a) without competition, (b) with a portion of the components in competition, and (c) with all components in competition. Lee (1960) grew "checkerboard" (spaced 10 cm apart) and bulk plots to compare measurements of competition when plants were known to be surrounded by plants of a second genotype and when neighboring plants were distributed at random, respectively.

Competitive abilities of genotypes have been determined by measuring changes in composition in variety mixtures when grown at one site or in a distinct environment over time

(Iwaki, 1959; Jennings and Aquino, 1968; Jennings and de Jesus, Jr., 1968). Sakai and Gotoh (1955) measured a genotype's competitive ability by the increment or decrement of certain plant traits when grown in mixed vs pure stands. Competitive ability has also been computed by path coefficients (Sano and Morishima, 1977) and variances and covariances of yield components (Hardwick and Andrews, 1980).

Blijenburg and Sneep (1975) developed a model to measure competition between plants that competed only for space. Jensen and Federer (1965) used Griffing's (1956) experimental method 1 to measure competitive interactions of strains grown side by side. They were able to estimate general, specific, and reciprocal competitive ability effects. Schutz et al. (1968) developed a method to determine the type of intergenotypic competitive effects in a population, and Brim and Schutz (1968) developed a formula to include within- and between-row sources of competition.

Competitive Ability Studies in Plant Breeding

Both the pedigree and bulk selection methods of plant breeding have been used to develop new varieties of self-pollinated species. The pedigree method makes use of selection among spaced plants that are not subject to competition from other plants (Allard, 1960). The bulk method, on the other hand, involves selection among plants in a heterogeneous population that has been grown _en masse_ for several generations and, thus, the plants have been subjected to competition (Jain, 1961). An important aspect of the bulk method is whether a correlation exists between agronomic productivity of a genotype and its competitive ability. For example, six barley composite crosses were grown in bulk for 6 to 24 generations and measured for persistence of specific characters and the progressive changes in yields of the composites (Suneson and Stevens, 1953). Progeny most like the adapted parents survived disproportionally well, which suggests that character associations, rather than specific characters, determined survival in a mixture. Four barley varieties, Atlas, Club Mariout, Hero, and Vaughn, were grown in a mixture (Suneson, 1949), and after seven years, Hero and Vaughn were virtually eliminated, and after 15 years, Atlas made up 88% of the population and Vaughn was completely eliminated.

Several studies have compared yields in early and succeeding generations of composite crosses carried via the bulk method. For wheat, intergenotypic competition had no significant effect on yield (Busch and Luizzi, 1979; Busch et al., 1974, 1976; Cregan and Busch, 1977). Harlan et al. (1940) grew 379 barley crosses in bulk for seven generations and found that the highest yielding segregates were from crosses with parents that were superior and had high competitive ability. Marshall (1976) grew F_3 and F_7 bulk populations of oats and found growth habits changed from intermediate to erect and decumbent, respectively. Jain (1961), using heterogeneous barley populations, observed a linear correlation between fitness and agronomic productivity, and the heterogeneous populations produced more stable yield across environments than did pure lines. Experiments with oats and soybeans have shown early generation tests to be of little value for predicting crosses that would produce outstanding lines in later generations (Atkins and Murphy, 1949; Leffel and Hanson, 1961; Weiss et al., 1947), perhaps because natural selection had caused modification via interplant competition as the bulks were propagated. Mumaw and Weber (1957) grew soybean composites for several years at the same location and found the composition changed due to natural selection, and Rasmusson et al. (1967) found a significant increase in a barley composite yield of 9.5% per year of propagation.

Jennings and Herrera (1968) found that semidwarf rice genotypes had greater yield potential in pure stands, but tall genotypes were more competitive in mixtures. Chatterjee and Bhattacharyya (1982) sowed two rice varieties in alternate rows and, in general, found neutral yield compensation, but certain combinations gave overcompensation.

Sakai (1955) studied the "effect of interaction operating between individuals of different genotypes within a population." He found that F_1 barley hybrids had lower competitive ability than their parents. Further, competitive pressure increased within a population as interplant space decreased.

Competitive Ability Studies in Agriculture

Survival of genotypes in bulk plots depends on the numbers of seeds the various genotypes produce and the proportion of the seeds that reach maturity and produce offspring (Allard, 1960). The effects of natural selection on mixtures were studied by blending widely adapted barley varieties (Harlan and Martini, 1938). Natural selection was a significant factor wherever the mixtures were grown, but there were great fluctuations in dominating genotypes among locations.

Competitive effects upon plants within heterogeneous lines are usually more variable than on those within homogeneous lines (Byth and Caldwell, 1970). Bussell (1937) and Zavitz (1927) found that small grain blends yielded near the mean of the components grown in pure stand, and Clay and Allard (1969), who used ten barley varieties to develop 23 mixtures, noted a distinct yield advantage for mixtures when averaged over environments. Reich and Atkins (1970) found that sorghum hybrid blends were more productive and stable, but no blend was distinctly superior. Fehr and Rodriguez (1974), Probst (1957), and Walker and Fehr (1978) blended soybeans to stabilize yield, but no yield advantage was found. Mixtures of oats and barley marginally outyielded the most productive species, and were more stable than barley or oats grown alone (Bebawi and Naylor, 1978).

Jensen (1952, 1965) reported that multilines had a 3.2% yield advantage over the mean of component lines. Murphy et al. (1982) grew an oat multiline to determine its stability of composition. One near-isogenic line, CI 9192, was reduced from 20 to 10%, and CI 9184 increased from 20 to 38%. They concluded that lines like CI 9184 cause instability in a multiline.

MATERIALS AND METHODS

Materials and Field Experiments

The materials used to study competitive ability consisted of two sets of oat isolines, a set of oat varieties, and a set with two barley and three oat varieties.

Experiment I: This experiment made use of five oat isolines, CI 8044, CI 9170, CI 9172, CI 9173, and CI 9178, from the Multiline E series (Frey and Browning, 1976b).

Experiment II: This experiment made use of five oat isolines, CI 9183, CI 9184, CI 9190, CI 9191, and CI 9192, from the Multiline M series (Frey and Browning, 1976a). These were the same isolines used in the study reported by Murphy et al. (1982).

Experiment III: This experiment made us of five midseason oat varieties, Benson (CI 9358), Chief (CI 9080), Garland (CI 7453), Noble (CI 9194), and Ogle (CI 9401).

Experiment IV: This experiment made use of two barley varieties, Minnesota M32 and Wisconsin W38 (CI 5105), and three oat entries, Cherokee (CI 3846), CI 9268, and Richland (CI 787).

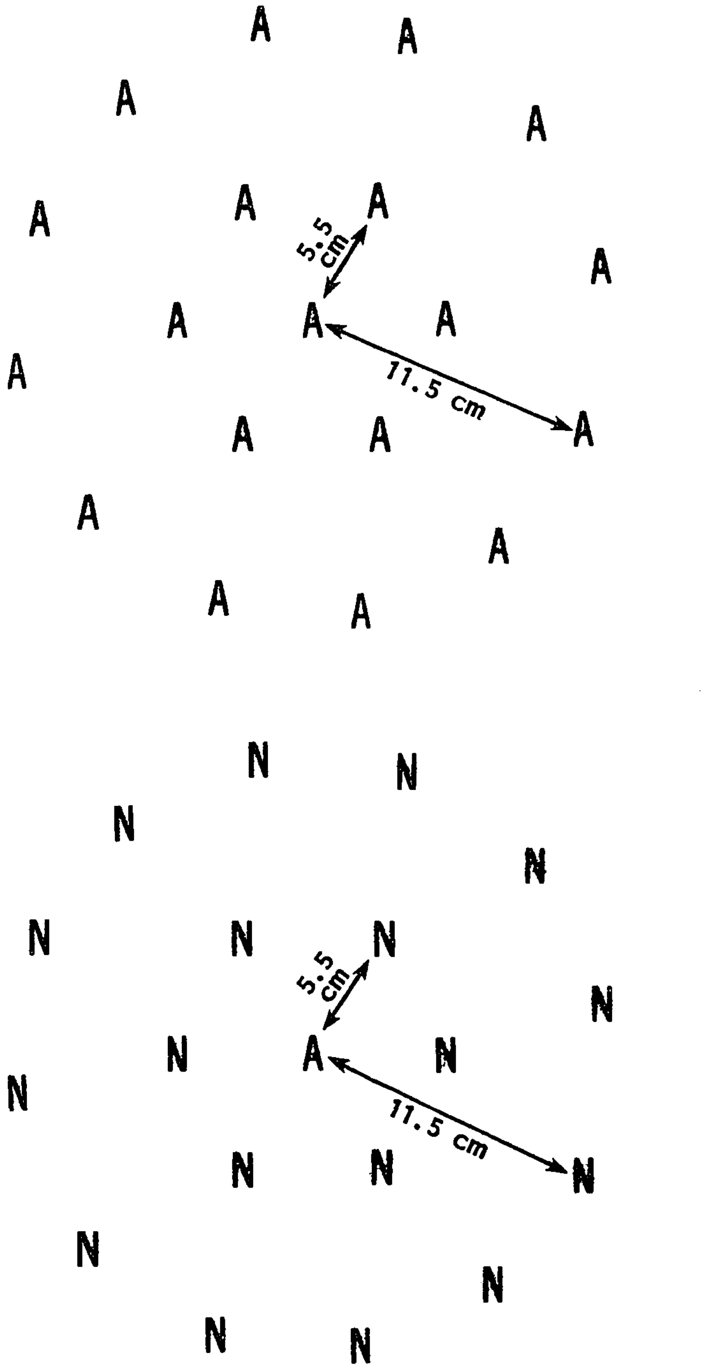
Experiments I-IV were grown in the field in 1982 and 1983. Plants of one genotype were sown in the center of each of paired hexagon plots (Sakai, 1955). The center plant in a plot was surrounded by 2 rows of plants, of its own genotype

(A^A) in one plot and of another genotype (A^N) in the paired plot (Figure 1). The inner and outer rows of competition contained six and twelve plants sown 5.5 and 11.5 cm, respectively, from the center plant. The arrangement and number of oat or barley seedlings in a plot gave a stand equivalent of 300 plants per m^2, the density commonly used in agricultural production. Basically, I used a split-plot design with the two paired hexagon subplots being randomized within each whole plot. For each experiment in each year, I used a randomized complete-block design with ten replications.

Water-soluble, polyethylene oxide sheets were used to facilitate sowing the plots in the field. A map of the planting arrangement (Figure 1) for one subplot was drawn on paper, and a sheet (30 x 30 cm) of transparent, polyethylene oxide was placed over the map. Next, three seeds were arranged at each point on the map. The polyethylene sheet was moistened with a fine mist of water, and a second sheet was placed over the arranged seed so that the top and bottom sheets stuck together and held the seeds in place. The laminated plastic sheets were then labeled and stacked in boxes for planting in the field.

To plant a plot in the field, I used a steel rake to remove soil to ca. a 5 cm depth from an area large enough to accommodate the 30 x 30 cm plastic sheet. Next, the laminated plastic sheet with the prearranged seed was placed in the

Figure 1. The planting arrangement used for Experiments I-IV; the center plant in a plot was surrounded by two rows of plants, of its own genotype (A) in one plot and of another genotype (B) in the paired plot


A A A A A A A A A A A A A A A A A A
5.5 cm
11.5 cm
N N N N N N N A N N N N N N N N N N
5.5 cm
11.5 cm

A

B

excavated area, and the sheet was covered with soil. When seedlings were at the two-leaf stage of development, they were thinned to one seedling per point as shown in Figure 1.

The experiments were sown on 22 April 1982 and 23 April 1983 on a Coland loam (Cumulic Haplaquolls) soil at the Hinds experimental farm near Ames, Iowa. The fertilization regime in 1982 consisted of a split application of N, P_2O_5, and K_2O topdressed onto the plots at rates of 28, 8, and 14 kg/ha, respectively, on 25 April; 17, 17, and 17 kg/ha, respectively, on 21 June; and 11, 10, and 10 kg/ha, respectively, on 1 July. In 1983, the rates of application were 28, 8, and 14 kg/ha, respectively, on 25 April; 17, 5, and 8 kg/ha, respectively, on 13 June; and 11, 3, and 6 kg/ha, respectively, on 25 June. Irrigation was used in both years to assure that the experimental areas were never deficient in available moisture. Each year the plants were sprayed with dimethoate at weekly intervals from emergence to anthesis to control aphids and leafhoppers, and with Maneb at weekly intervals from anthesis to maturity to control foliar diseases. The plots were hand weeded.

Collection of Data

Data were collected only for the center plant of each plot. Days to heading was recorded for a plant as the number of days from planting until the primary panicle was completely emerged.

At maturity, the test plant in each plot was harvested at ground level and dried. Biomass yield was recorded as the weight (in g) of the culms from a plot, after which the number of culms was counted and mean height was recorded in cm. The total number of spikelets for each of the barley and oat plants were recorded, and for the oat plants, the spikelets were classified into the number of primary and secondary florets (seeds) which developed. These seeds were then weighed and grain yield was recorded in g.

Statistical Procedures

Means for a trait when a genotype was competing with itself and with another genotype were computed across replications and years, and the paired means were tested for similarity by a t-test as follows:

$$t = \frac{\bar{X}_c - \bar{X}_p}{\sqrt{\frac{\sigma_c^2}{n_1} + \frac{\sigma_p^2}{N_2}}}$$

where $\bar{X}_c$ is the mean of the genotype in competitive stand, $\bar{X}_p$ the mean of the genotype in pure stand, σ_c^2 and σ_p^2 the variance of the genotypes in competitive and pure stands, respectively, and n_1 and n_2 the number of observations for competitive and pure stands, respectively.

RESULTS

To determine the competitive ability of an entry, relative to other entries in its group, I computed the mean difference between its performance when grown in a competitive (C) stand with another variety and when grown in pure (P) stand. Results for these competitive-entry (c-entry) and pure-entry (p-entry) comparisons are presented in the Appendix with one table for each trait in each experiment. For ease of presentation, however, means and ranges for all c- and p-entry comparisons involving a given entry are presented in Tables 1, 2, 3, and 4 for Experiments I, II, III, and IV, respectively.

Experiment I

The entries in Experiment I were CI 8044, the basic genotype used for Multiline E77 oat variety and four isolines of CI 8044, each of which carried a unique gene that conditioned host resistance to the crown-rust pathogen (*Puccinia coronata* Cda. *avenae* Frazier and Ledingham). CI 9170, CI 9172, CI 9173, and CI 9178 are four of the nine isolines used to compose Multiline E77 variety.

When CI 8044 was measured for competitive ability against the other four entries, the mean effect on biomass was zero (Table 1). However, it varied considerably in competitive ability, measured via biomass, when competing with the other

Table 1. Means and range of the differences for biomass, grain yield, numbers of spikelets, primary florets, secondary florets, and tillers per plant, heading date, and height when the entries used in Experiment I were grown in competitive and pure stands

	Trait							
Entry	Biomass (g)	Grain yield (g)	Spikelets	Primary florets	Secondary florets	Tillers	Heading date (days)	Height (cm)
CI 8044								
Mean	0.0	0.3	3.0	4.0	2.0	0.0	-1.0	-1.0
Range	-0.9 - 1.7	-0.3 - 1.0	-6.0 - 19.0	-7.0 - 20.0	-8.0-18.0	-0.2 - 0.2	-5.0 - 1.0	-6.0 - 11.0
CI 9170								
Mean	-0.2	0.0	-3.0	-2.0	-1.0	-0.2	0.0	4.0
Range	-0.8 - 0.2	-0.4 - 0.2	-9.0 - 3.0	-7.0 - 2.0	-7.0 - 3.0	-0.4 - 0.0	-1.0 - 2.0	-0.4 - 0.0
CI 9172								
Mean	0.3	0.0	0.0	1.0	1.0	0.0	0.0	-1.0
Range	-1.0 - 1.5	-0.6 - 0.6	-0.9 - 8.0	-8.0 - 9.0	-7.0 - 7.0	-0.1 - 0.2	-1.0 - 1.0	-3.0 - 2.0
CI 9173								
Mean	-0.2	-0.1	-1.0	-3.0	-3.0	-0.1	0.0	2.0
Range	-1.0 - 0.5	-0.7 - 0.2	-11.0 - 5.0	-10.0 - 3.0	-9.0 - 2.0	-0.3 - 0.1	0.0 1.0	-7.0 - 10.0
CI 9178								
Mean	0.4	0.3	7.0	5.0	6.0	0.0	0.0	5.0
Range	-0.8 - 2.2	-0.2 - 0.5	-5.0 - 17.0	-1.0 - 10.0	-2.0 - 11.0	-0.2 - 0.2	-2.0 - 0.0	-1.0 - 14.0

four isolines. It was inferior in competition with CI 9170, CI 9173, and CI 9178, but 1.7*** g per plant superior in competition with CI 9172 (Table 5, Appendix). Grain yield of CI 8044, on average, was 0.3 g per plant greater in competitive than in pure stands (Table 1). The difference for this trait ranged from -0.3 to 1.0 g per plant. As with biomass, CI 8044 was significantly superior in competitive stand when the competitor was CI 9172 (Table 6, Appendix). The slight mean superiority of CI 8044 for grain yield (+0.3 g per plant), in competitive stands, appeared to be caused by increased spikelet number. Secondarily, greater mean spikelet number (3.0) resulted in increased numbers of primary and secondary florets when grown with CI 9172. It had 19.0*** additional spikelets and 20.0*** and 18.0*** additional primary and secondary florets, respectively (Tables 7-9, Appendix). Heading date of CI 8044 averaged one day earlier when grown in competition with the other isolines (Table 1). In one c- and p-entry comparison, that with CI 9170, the heading date of CI 8044 was significantly earlier (5.0*** days) than when grown in pure stand (Table 11, Appendix). Competition with other isolines had little effect on the number of tillers developed by CI 8044 (Table 1); however, competition had a decided but variable effect on height. It ranged from a significant reduction (6.0** cm) to a significant increase (11.0*** cm) when grown in competition with CI 9170 and

CI 9172, respectively (Table 12, Appendix). Overall, height of CI 8044 was reduced 1.0 cm in competitive stands (Table 1).

Biomass of CI 9170 was reduced slightly by competition from other isolines, but there was no mean change in grain yield (Table 1). Interestingly, all components of yield that were measured, i.e., numbers of spikelets, primary and secondary florets, and tillers per plant were decreased slightly by competition even though yield was unchanged (Table 1). This would lead one to expect that competition resulted in increased seed weight for CI 9170; however, this trait was not evaluated. Heading date of CI 9170 was delayed 2.0** days when CI 9173 was its competitor, but, on average, competition had no effect on this trait (Table 11, Appendix). When CI 9173 was the competitor isoline, the height of CI 9170 was significantly increased (9.0** cm) (Table 12, Appendix). Over all c- and p-entry comparisons, plant height of CI 9170 increased 4.0 cm in competitive stands (Table 1). CI 9173 was the only isoline that had a marked effect on CI 9170, and then, only upon heading date and plant height.

The average biomass of CI 9172 increased 0.3 g per plant in competitive stands (Table 1), but much of this increase was due to the 1.5* g increase when CI 9178 was the competitor (Table 5, Appendix). The biomass increase was not reflected in grain yield as shown by the fact that CI 9172 yielded 1.6 g per plant in both competitive and noncompetitive stands (Table 6, Appendix). Averaged across all four comparisons, competition caused no effect on number of spikelets or number of tillers per plant, but numbers of primary and secondary florets were each increased by 1.0. Neither heading date nor plant height of CI 9172 was affected materially by competition from other isolines. When tested against competitor isolines, CI 9172 was quite neutral.

On average, all yield and yield component traits of CI 9173 were reduced slightly in competitive stands (Table 1). The biomass of CI 9173 was affected variably by competition. CI 8044 and CI 9170 as competitors had little effect on biomass of CI 9173, but CI 9172 and CI 9178 caused a sizable decrease and increase, respectively (Table 5, Appendix). Grain yield of CI 9173 was significantly reduced when CI 9172 was its competitor (Table 6, Appendix). Number of spikelets and number of primary and secondary florets were reduced generally, and significantly, when CI 9172 was the competitor (Tables 7-9, Appendix). Overall, these traits were reduced by 1.0, 3.0, and 3.0, respectively (Table 1). The effect of competitor isolines on plant height of CI 9173 was a 2.0-cm increase, on average, but the results from different c- and p-entry comparisons were highly variable (Table 1). CI 9172 caused a 7.0-cm decrease, whereas CI 9178 resulted in a 10.0*-cm increase (Table 12, Appendix).

On average, CI 9178 benefited from competitive stands, or, in other words, it was a good competitor against the other isolines. Its mean biomass was increased by 0.4 g per plant (Table 1), but the major portion for this general increase was due to its superiority when CI 9170 was the competitor (Table 5, Appendix). It had nearly an 80% advantage in this c- and p-entry comparison. Overall, the grain yield increase was 0.3 g per plant in competitive stands (Table 1), but c- and p-entry combinations resulted in both significant increases and decreases in grain yield (Table 6, Appendix). Overall, 7.0 additional spikelets developed when CI 9178 was grown in competitive stands, and primary and secondary florets increased by 5.0 and 6.0, respectively (Table 1). The effects of specific c- and p-entry combinations varied greatly for numbers of spikelets and florets per plant, but the greatest effect always occurred when CI 9170 was the competitor (Tables 7-9, Appendix). No difference was found in tiller number due to competition, but height increased 5.0 cm in competitive stands (Table 1) and CI 9178 was significantly taller (14.0** cm) when CI 9170 was the competitor (Table 12, Appendix).

Of the isolines in Experiment I, CI 9178 showed the greatest positive response in competitive stands. It showed the highest response in competitive stands for biomass, grain yield, and numbers of spikelets and primary and secondary florets (Table 1). CI 8044 showed the second highest response even though biomass was unchanged. Grain yield and its related traits, numbers of spikelets and primary and secondary florets increased in competitive stands (Table 1). CI 9172 showed a moderate increase in biomass, whereas grain yield and its related traits were unchanged in competitive stands (Table 1). The isolines CI 9170 and CI 9173 were both poor competitors. They tended to show negative responses to competition.

Experiment II

The entries CI 9183, CI 9184, CI 9190, CI 9191, and CI 9192 in Experiment II were five of the isolines used to compose the oat Multiline M73 variety, and the exact isolines used by Murphy et al. (1982) in their study on modification of multiline composition.

When CI 9183 was measured for competitive ability against the other four entries, the mean effect on biomass was zero (Table 2). Grain yield of CI 9183, on average, was 0.1 g per plant less in competitive than in pure stands (Table 2). The slight decrease in grain yield appeared to be due to decreased spikelet number. The average decrease in spikelet number (1.0) was reflected in average decreases of 3.0 in number of primary and secondary florets (Table 2). Competition had no effect on heading date of CI 9183 in any c- and p-entry comparisons and the mean effect on plant height was

Table 2. Means and range of the differences for biomass, grain yield, numbers of spikelets, primary florets, secondary florets, and tillers per plant, heading date, and height when the entries used in Experiment II were grown in competitive and pure stands

	Trait							
Entry	Biomass (g)	Grain yield (g)	Spikelets	Primary florets	Secondary florets	Tillers	Heading date (days)	Height (cm)
CI 9183								
Mean	0.0	-0.1	-1.0	-3.0	-3.0	-0.1	0.0	0.0
Range	-0.5 - 0.3	-0.3 - 0.1	-7.0 - 6.0	-10.0 - 2.0	-10.0 - 4.0	-0.3 - 0.2	0.0	-9.0 - 6.0
CI 9184								
Mean	-0.2	-0.2	-4.0	-2.0	-4.0	0.1	1.0	3.0
Range	-0.7 - 0.9	-0.4 - 0.1	-12.0 - 4.0	-10.0 - 3.0	-8.0 - 1.0	-0.1 - 0.3	-1.0 - 1.0	-4.0 - 11.0
CI 9190								
Mean	0.1	0.4	2.0	0.0	0.0	0.0	0.0	-1.0
Range	-0.5 - 0.7	-0.4 - 1.7	-6.0 - 9.0	-9.0 - 5.0	-12.0 - 6.0	-0.3 - 0.4	-2.0 - 1.0	-8.0 - 6.0
CI 9191								
Mean	0.3	0.2	4.0	3.0	3.0	0.1	-1.0	1.0
Range	-0.4 - 1.0	-0.4 - 0.6	-8.0 - 16.0	-10.0 - 16.0	-10.0 - 17.0	-0.2 - 0.7	-1.0 - 1.0	-3.0 - 7.0
CI 9192								
Mean	1.2	0.6	10.0	11.0*	11.0*	0.0	-1.0	-2.0
Range	-0.3 - 2.9	0.1 - 1.2	-3.0 - 22.0	0.0- 22.0	3.0 - 26.0	-0.4 - 0.4	-3.0 - 0.0	-14.0 - 11.0

*Significant at the 10% level.

zero (Table 2). In none of the c- and p-entry comparisons involving CI 9183 was there a significant difference between its performance in competitive and pure stands. This indicates that CI 9183 was neutral with respect to competitive ability with the other isolines.

When averaged across all four c- and p-entry comparisons, biomass and grain yield of CI 9184 each decreased 0.2 g per plant in competitive stands (Table 2). When CI 9183, CI 9190, and CI 9191 were the competitors, grain yield of CI 9184 was decreased 0.3 to 0.4 g per plant, but with CI 9192 as the competitor, it was increased 0.1 g per plant (Table 14, Appendix). The mean decrease in grain yield was accounted for by decreases in numbers of spikelets and primary and secondary florets by 4.0, 2.0, and 4.0, respectively (Table 2). Competition with other isolines had little effect on the number of tillers or heading date of CI 9184 (Table 2). However, plant height of CI 9184 was increased 3.0 cm, on average (Table 2), and where CI 9192 was the competitor, it increased significantly (11.0* cm) (Table 20, Appendix).

Biomass of CI 9190, on average, was 0.1 g per plant greater in competitive than in pure stands (Table 2), but grain yield increased 0.4 g per plant in competitive stands (Table 2). Most of the grain yield increase was due to the 1.7*** g per plant superiority when CI 9183 was the competitor (Table 14, Appendix). Spikelet number was increased by 2.0

in competitive stand, but numbers of primary and secondary florets were unchanged (Table 2). Secondary floret number significantly decreased (12.0**) when CI 9192 was the competitor, but in the other three c- and p-entry comparisons, competition resulted in increased secondary floret number (Table 17, Appendix). Small plus and minus changes occurred in tillers per plant and heading date of CI 9190, but the overall effect was zero for both traits (Table 2).

Biomass of CI 9191 was increased 0.3 g and grain yield 0.2 g per plant when grown in competitive stands (Table 2), neither of which was a significant effect. The grain yield increase could be accounted for by increases in number of spikelets and primary and secondary florets of 4.0, 3.0, and 3.0, respectively, when CI 9191 was grown in competitive stands (Table 2). Over all c- and p-entry comparisons, there was little effect on tillers per plant, but when CI 9184 was the competitor isoline, this trait was increased by more than 50%. In fact, the increased tillers per plant also account for the sizable increases in numbers of spikelets and primary and secondary florets per plant and ultimately grain yield. Heading date was delayed one day, on average, and height was increased 1.0 cm in competitive stands (Table 2).

Average biomass of CI 9192 increased 1.2 g per plant when in competitive stands (Table 2). This represents a 43% increase. When paired on a c- and p-entry basis with CI 9184, CI 9190, and CI 9191, CI 9192 showed 2.9*, 1.5, and 0.7 g per plant advantages, respectively, in competitive stands, but it was 0.3 g per plant inferior in biomass when the competitor was CI 9183 (Table 13, Appendix). The biomass superiority of CI 9192 in competitive stands was reflected in a grain yield superiority also. The grain yield advantage in competitive stands was 0.6 g per plant (Table 2). In fact, competitive stands gave greater grain yields than pure stands for all c- and p-entry comparisons in which CI 9192 was tested. The competitive stand advantage ranged from 0.1 to 1.2 g per plant (Table 14, Appendix). The 45% grain yield advantage for CI 9192 in competitive stands was due to greater numbers of spikelets (10.0) and primary (11.0*) and secondary (11.0*) florets per plant (Table 2). Competition with other isolines had no overall effect on the number of tillers per plant for CI 9192 (Table 2), so the competitive advantage for this line resulted from larger panicles. Overall, the heading date of CI 9192 was one day earlier in competitive stands (Table 2), and when grown with CI 9191 as the competitor, it was significantly earlier (3.0*** days) than when grown in pure stand (Table 19, Appendix). Plant height of CI 9192 was decreased 2.0 cm by competition (Table 2), and as much as 14.0* cm when CI 9191 was its competitor (Table 20, Appendix).

Among the isolines in Experiment II, CI 9192 gave the greatest response in competitive stands. Its biomass was increased by 43% and its grain yield by 45% when grown in competition with the other isolines (Table 2). CI 9192 even showed significant competitive advantages for numbers of primary and secondary florets. CI 9191 was also responsive in competitive stands. Its biomass and grain yield were increased by 10% and 13%, respectively. For CI 9191, grain yield and its components, numbers of spikelets and primary and secondary florets, increased slightly in competitive stands. Biomass of CI 9190 increased only slightly, whereas grain yield increased by 25% in competitive stands (Table 2). Of the yield related traits measured for this isoline, i.e., number of spikelets, primary and secondary florets, and tillers per plant, only number of spikelets increased in competitive stands. Thus, increased grain yield for this entry in competitive stands must have resulted from increased seed weights. CI 9183 and CI 9184 tended to be slightly inferior for biomass, grain yield, and yield related traits when grown in competitive stands.

It is interesting that each isoline in Experiment II that showed a grain yield superiority, in competitive stand, used a different yield component to contribute that superiority. CI 9190 probably had increased seed weight in competitive stands, CI 9191 had increased tillers per plant, and CI 9192 had larger panicles.

Experiment III

The midseason oat varieties, Benson, Chief, Garland, Noble, and Ogle, were grown in Experiment III to ascertain their competitive characteristics in a blend.

When Benson was measured for competitive ability against the other four entries, the mean effect on biomass was zero (Table 3). Grain yield per plant for Benson was variable, but increased only 0.1 g per plant in competitive stands (Table 3). The slight increase in grain yield was accompanied by an increase in numbers of spikelets (5.0) and primary (3.0) florets. Grain yield decreased when Chief and Ogle were the competitors and increased when Garland and Noble were the competitors (Table 22, Appendix). Interestingly, even though Chief reduced grain yield of Benson in competitive stands, the number of spikelets increased by 10.0 (Table 23, Appendix) and tillers by 0.2 (Table 26, Appendix). Probably, seed weight was reduced in competitive stands. Heading date of Benson was delayed 3.0*** days when Garland was its competitor (Table 27, Appendix) and, on average, heading date occurred 1.0 day earlier in competitive than in pure stands (Table 3). Height was variable in competitive stands (Table 28, Appendix), but, on average, it was decreased 1.0 cm in competitive stands (Table 3).

On average, grain yield and yield component traits of Chief were unaffected or only slightly decreased in competi-

Table 3. Means and range of the differences for biomass, grain yield, numbers of spikelets, primary florets, secondary florets, and tillers per plant, heading date, and height when the entries used in Experiment III were grown in competitive and pure stands

	Trait							
Entry	Biomass (g)	Grain yield (g)	Spikelets	Primary florets	Secondary florets	Tillers	Heading date (days)	Height (cm)
Benson								
Mean	0.0	0.1	5.0	3.0	0.0	0.2	-1.0	-1.0
Range	-0.7 - 0.6	-0.6 - 0.5	-8.0 - 10.0	-1.0 - 10.0	-8.0 - 7.0	0.0 - 0.3	-3.0 - 0.0	-10.0 - 8.0
Chief								
Mean	0.0	-0.1	0.0	-1.0	-1.0	-0.1	0.0	0.0
Range	-0.3 - 0.3	-0.3 - 0.1	-7.0 - 6.0	-6.0 - 4.0	-5.0 - 1.0	-0.4 - 0.1	-1.0 - 1.0	-13.0 - 8.0
Garland								
Mean	-0.4	-0.1	-4.0	-1.0	-2.0	-0.1	1.0	2.0
Range	-1.2 - 0.4	-0.6 - 0.4	-14.0 - 10.0	-11.0 - 13.0	-7.0 - 7.0	-0.6 - 0.2	-1.0 - 3.0	1.0 - 12.0
Noble								
Mean	0.2	0.0	-1.0	0.0	-1.0	0.1	1.0	4.0
Range	-0.5 - 0.8	-0.2 - 0.3	-6.0 - 4.0	-2.0 - 4.0	-3.0 - 3.0	0.0 - 0.1	-1.0 - 3.0	-1.0 - 8.0
Ogle								
Mean	0.3	0.0	2.0	4.0	3.0	0.1	0.0	4.0
Range	-0.1 - 0.5	-0.2 - 0.4	-4.0 - 9.0	-2.0 - 12.0	-3.0 - 11.0	-0.3 - 0.4	0.0 1.0	-2.0 10.0

tive stands (Table 3). Thus, when tested against the other varieties as competitors, Chief was neutral to competitive effects. One c- and p-entry comparison of interest involved Noble as the competitor. Chief grew 8.0 cm taller, produced greater numbers of spikelets (6.0) and primary (4.0) and secondary (1.0) florets when Noble was the competitor (Tables 23-25, Appendix). Since grain yield did not increase due to enlarged panicle size, seed weight must have decreased when Noble was the competitor for Chief.

Biomass of Garland was reduced, on average, 0.4 g per plant in competitive stands (Table 3), but a major portion of this decrease occurred when Noble was the competitor (Table 21, Appendix). The biomass decrease for Garland when Noble was the competitor was accompanied by a decrease of 0.6** tillers per plant (Table 26, Appendix). Grain yield of Garland decreased when Benson, Chief, and Noble were the competitors, and increased only when Ogle was the competitor (Table 22, Appendix). The slight mean decrease in grain yield appeared to be due to decreased spikelet number. The average decrease in spikelet number (4.0) was reflected in average decreases of 1.0 and 2.0 in numbers of primary and secondary florets, respectively (Table 3). On average, heading date of Garland was 1.0 day later in competitive stands (Table 3), but when Benson was its competitor, this trait was delayed 3.0** days (Table 27, Appendix). Garland was 2.0 cm taller in competitive stands (Table 3).

Biomass of Noble was increased slightly by competition from other varieties, but there was no mean change in grain yield (Table 3). Numbers of spikelets, primary and secondary florets, and tillers per plant were virtually unaffected by competition (Table 3). These traits did show a slight increase when Ogle was the competitor (Tables 23-26, Appendix). Overall, heading date of Noble was delayed 1.0 day (Table 3), and was significantly delayed (3.0*** days) when Benson was its competitor (Table 27, Appendix). Height ranged from 1.0 cm shorter to 8.0 cm taller in competitive stands, but no c- and p-entry comparison was significant (Table 28, Appendix).

Biomass of Ogle increased 0.3 g per plant in competitive stands, but the increase was only 0.1 g per plant for grain yield (Table 3). Ogle was inferior in competitive stands only when Benson was the competitor (Table 22, Appendix). All yield related traits, numbers of spikelets, primary and secondary florets, and tillers per plant, increased somewhat in competitive stands (Table 3). Numbers of primary and secondary florets increased 12.0* and 11.0*, respectively, when Garland was the competitor for Ogle (Tables 24 and 25, Appendix). Heading date was unaffected, but plant height was increased 4.0 cm by competition from other varieties.

Overall, no one entry in Experiment III was superior in competitive stands, but, generally, Garland was somewhat inferior. C-entry and p-entry comparisons which showed competitive advantages indicated that instances of superiority for grain yield were associated with increased numbers of spikelets and primary and secondary florets.

Experiment IV

The entries used in Experiment IV were two barley varieties, Minnesota M32 and Wisconsin W38, and three oat varieties, Cherokee, CI 9268, and Richland. This combination of entries was chosen to compare interspecific competitive abilities.

Mean biomass of Cherokee was decreased 0.4 g per plant (Table 4), but the major portion of this general decrease was due to its inferiority when M32 barley was the competitor (Table 29, Appendix). Grain yields of this variety were both increased and decreased in competitive stands with the other four entries, but, on average, the effect of competition was zero (Table 4). There was a general decrease in all yield components of Cherokee, but M32 as the competitor caused significant reductions in numbers of spikelets and primary florets. Also, plant height was significantly reduced (17.0** cm) when M32 was the competitor (Table 36, Appendix). Number of tillers per plant was reduced 0.6* when M32 was the competitor of Cherokee which may have caused the biomass decrease (Table 34, Appendix).

Over all c- and p-entry comparisons, biomass of CI 9268

Table 4. Means and range of the differences for biomass, grain yield, numbers of spikelets, primary florets, secondary florets, and tillers per plant, heading date, and height when the entries used in Experiment IV were grown in competitive and pure stands

Entry	Trait							
	Biomass (g)	Grain yield (g)	Spikelets	Primary florets	Secondary florets	Tillers	Heading date (days)	Height (cm)
Cherokee								
Mean	-0.4	0.0	-1.0	-3.0	-1.0	-0.1	-1.0	-6.0
Range	-2.0 - 0.6	-0.6 - 0.4	-14.0 - 6.0	-14.0 - 4.0	-10.0 - 6.0	-0.6 - 0.2	-3.0 - 2.0	-17.0 - -2.0
CI 9268								
Mean	0.6	0.4	9.0	8.0	5.0	0.3	0.0	2.0
Range	-0.9 - 1.7	-0.4 - 0.8	-6.0 - 17.0	-7.0 - 17.0	-9.0 - 14.0	-0.1 - 0.6	-3.0 - 0.0	-9.0 - 10.0
M32								
Mean	0.7	0.2	6.0	-	-	0.5	-1.0	5.0
Range	0.2 - 1.7	0.1 - 0.5	1.0 - 13.0	-	-	0.4 - 0.7	-4.0 - 1.0	-8.0 - 17.0
Richland								
Mean	0.4	0.0	-3.0	-2.0	-2.0	-0.1	0.0	3.0
Range	-1.8 - 1.8	-0.9 - 0.8	-36.0 - 22.0	-31.0 - 14.0	-32.0 - 17.0	-0.7 - 0.4	-1.0 - 2.0	-11.0 - 15.0
W38								
Mean	-0.9	-0.5	-7.0	-	-	-0.3	-1.0	1.0
Range	-3.4 - 1.6	-1.5 - 0.7	-21.0 - 2.0	-	-	-0.7 - 0.1	-4.0 - 2.0	-6.0 - 6.0

increased 0.6 g per plant in competitive stands (Table 4). This trait was significantly increased (1.7* g) when Cherokee was the competitor (Table 29, Appendix). Grain yield of CI 9268, on average, was 0.4 g per plant greater in competitive than in pure stands (Table 4). The mean increase in grain yield, in competitive stands, appeared to be caused by increased numbers of spikelets (9.0) and primary and secondary florets (Table 4). Spikelet number of CI 9268 increased significantly (17.0* and 12.0*) when Cherokee and M32, respectively, were the competitors (Tables 31 and 32, Appendix), and secondary florets increased by 14.0* when Cherokee was the competitor (Table 33, Appendix). Tiller number was significantly increased (0.6*) when M32 was the competitor (Table 32, Appendix).

Mean biomass of M32 increased 0.7 g per plant in competitive stands (Table 4), but much of this increase was due to the 1.7** g increase when Cherokee was the competitor (Table 29, Appendix). On average, grain yield increased 0.2 g per plant (Table 4). M32 gave greater biomass and grain yield in competitive stands when any entry was the competitor. The grain yield superiority of M32 in competitive stands resulted because 6.0 more spikelets developed per spike (Table 4). The superiority for this trait was 13.0** when CI 9268 was the competitor (Table 31, Appendix). Averaged across all four competitors, tillers per plant increased 0.5 (Table 4), and this trait was increased significantly (0.6** and 0.7**) when Richland and W38, respectively, were the competitors (Table 34, Appendix). The effect of competition on heading date was variable, ranging from 4.0 days earlier to 1.0 day later in competitive than in pure stands (Table 4). When CI 9268 was the competitor, heading occurred significantly earlier (4.0*** days). Overall, plant height was increased 5.0 cm in competitive stands (Table 4), but much of this was due to a 17.0*** cm advantage when Cherokee was the competitor (Table 36, Appendix).

Biomass of Richland decreased 1.8*** g per plant and increased 1.8* g per plant when Cherokee and M32, respectively, were the competitors (Table 29, Appendix), but overall, this trait was increased 0.4 g per plant in competitive stands (Table 4). The biomass superiority was not reflected in a grain yield superiority in competitive stands (Table 30, Appendix). Numbers of spikelets and primary and secondary florets were decreased somewhat in competitive stands (Table 4). Tillers per plant decreased significantly (0.7***) when Cherokee was the competitor for Richland and this resulted in a decrease in biomass (Table 34, Appendix). Overall plant height was 3.0 cm taller in competitive stands. An increase in biomass resulted due to a significant increase in height (15.0** cm) when M32 was the competitor (Table 36, Appendix).

Averaged over four comparisons, competition caused decreased biomass, grain yield, and yield related components for W38 barley. Biomass decreased, on average, 0.9 g per plant or about 20% (Table 4). Major decreases occurred when Cherokee and Richland (1.6** g and 3.4** g per plant, respectively) were the competitors (Table 29, Appendix). These two varieties also affected grain yield and spikelet number similarly (Tables 30 and 31, Appendix). Overall, tillers per plant were reduced 0.3 per plant (Table 4), but when Richland was the competitor, this trait was decreased 0.7** (Table 34, Appendix). CI 9268 caused W38 to head 4.0*** days early (Table 35, Appendix), and, on average, W38 headed 1.0 day earlier in competitive than in pure stands (Table 4).

Most noticeable in Experiment IV was the fact that competition among the five entries resulted in much greater changes in trait expression than occurred in the other three experiments where only oat entires were used as competitors. Of the two barley varieties, M32 was a strong and W38 a weak competitor. Biomass, grain yield, and numbers of spikelets increased when M32 was grown in competitive stands, whereas these traits decreased in W38. The oat variety CI 9268 was a strong competitor. Its biomass, grain yield, and yield related traits increased in competitive stands. The oat varieties, Cherokee and Richland, generally were neutral as competitors. They showed decreased numbers of spikelets and primary and secondary florets in competitive stands, with no change in grain yields and either plus or minus changes in biomass.

DISCUSSION

Competitive ability of a plant genotype in a mixture is determined by the interaction of many plant traits. Lee (1960) determined that Atlas had a competitive advantage over Vaughn barley because it had greater tiller production and survival, whereas Khalifa and Qualset (1974) found genotypic predominance in wheat was related to plant height. Competitiveness of rice genotypes in mixtures was associated with plant height and tillering ability (Jennings and de Jesus, Jr., 1968). Results for varietal survival in mixtures of barley (Edwards and Allard, 1963; Lee, 1960; Suneson, 1949), soybeans (Mumaw and Weber, 1957), and rice (Jennings and de Jesus, Jr., 1968) have shown no positive relationship between yielding ability of an entry in pure stands and its survival in mixed stands.

Sakai and his colleagues (Sakai, 1955, Sakai and Gotoh, 1955; Sakai and Suzuki, 1955a,b) concluded that, in barley and rice, competitive ability was an inherited trait that was independent of any other trait they measured. Schutz and Brim (1967) identified differences in competitive abilities among soybean varieties, and they divided competitive relationships among entries into four categories, neutral, complementary, undercompensation, and overcompensation. Competitive ability of one rice genotype may result in the decline or complete elimination of another genotype from a mixture (Jennings and de Jesus, Jr., 1968; Oka, 1960).

My results, when averaged for an experiment, showed some evidence for overcompensation in Experiments I and II but not in Experiments III and IV. This was reflected by the fact that, for Experiments I, II, III, and IV, biomass was increased 3%, 9%, 0%, and 0%, respectively, in competitive stands.

Further examination of the results showed, however, that the entries within an experiment were highly variable with respect to mean of competitive reactions. In Experiment I, where early season isolines were evaluated, biomass change due to competition ranged from a 6% mean reduction for CI 9173 to an 11% increase for CI 9178. The mean biomass changes in Experiment II, where midseason oat isolines were evaluated, ranged from -3% for CI 9184 to 43% for CI 9192. The changes in biomass due to competition in Experiment IV, where oat and barley varieties were evaluated, ranged from a 24% reduction for W38 to a 25% increase for M32. The extreme entries were both barley varieties, but Cherokee, CI 9268, and Richland oats had mean changes due to competition of -13, 22, and 15%, respectively. In Experiment III, biomass changes ranged from -14 to 10%.

When one looks at the competitive effects for individual pairs of entries, the effects of competition were even more variable, as would probably be expected. In Experiments I and II, a large mean deviation for one entry most often was caused by an exceptionally large competitive advantage or disadvantage that occurred for only one paired comparison. For instance, the competitive effect on CI 8044 biomass was not significant when CI 9170, CI 9173, and CI 9178 were the competitors, but it was significant when CI 9172 was the competitor (Table 5, Appendix). On the other hand, in Experiment II, CI 9192 showed decided advantages in competitive stands when three of the isolines, CI 9190, CI 9191, and CI 9184, were its competitors, even though only the advantage with CI 9184 was significant (Table 13, Appendix).

With the more diverse set of entries in Experiment IV, the competitive advantage or disadvantage shown by an entry tended to be consistent across all competitors. For example, the biomass of W38 barley was reduced by three of the four competitors, and the reductions were significant when Cherokee and Richland oats were its competitors (Tables 29 and 30, Appendix). The increase in biomass for M32 barley resulted from this entry showing a competitive advantage over all four of its competitors.

There is no theory upon which to base an expectation about the types of competitive abilities that should be expected for a series of plant genotypes. First and foremost, the competitive ability of a genotype can only be evaluated relative to the genotypes that serve as competitors. Thus, Atlas barley, which has been shown to have such a consistent and marked competitive advantage over Vaughn variety (Lee, 1960), might not have a competitive advantage if the competitor was a different genotype than Vaughn. The growing of mixtures of small grain varieties tends to give from 0 to 5% increases in grain yield over the mean of the components grown in pure stand (Jensen, 1952; Frey and Maldonado, 1967). In my study, the experiments with the most diverse genotypes (i.e., Experiments III and IV) showed no overall increase in biomass production in competitive stands, whereas Experiments I and II, which contained groups of isolines, showed 3% and 9%, respectively, overall increases in biomass in competitive stands. This was somewhat surprising because the isolines should be so similar in physiology and morphology that competitive and pure stands should be equivalent. On the other hand, Frey (1972) and Frey and Browning (1971) have shown that certain isolines in both the Multiline E and Multiline M series were either significantly above or below the recurrent parent for grain yield and grain yield response to improving environments. The isolines grown in Experiments I and II were ten of the isolines used by Frey (1972) and Frey and Browning (1971) in their studies. A good correlation existed between my results and those of Frey (1972) and Frey and Browning (1971) for the early isolines. CI 8044 had the highest grain yield in both studies and CI 9173 the lowest, whereas CI 9170, CI 9172, and CI 9178 were intermediate in grain yield. A correlation did not exist between my results and those of Frey (1972) and Frey and Browning (1971) for the midseason isolines. They found that CI 9184 was superior and CI 9192 was inferior in grain yield. My results, on the other hand, showed that CI 9192 had superior grain yield and CI 9184 was inferior in grain yield. Therefore, my ratings for the midseason isolines and those from Frey (1972) and Frey and Browning (1971) are diametrical.

In my study, competitive advantages or disadvantages displayed by oat and barley genotypes for biomass and grain yield usually could be related to biomass or grain yield components. For instance, when CI 9172 was the competitor for CI 8044, a significant increase occurred for biomass and grain yield of CI 8044, and these increases were reflected in significant increases in numbers of spikelets and primary and secondary florets. It is also interesting that, in Experiment II, different yield components contributed to competitive advantage in biomass and grain yield of different genotypes. Grain yield of CI 9190 increased 0.4 g per plant in competitive stands (Table 2). Spikelet number was increased by 2.0 in competitive stand, but numbers of primary and secondary florets were unchanged (Table 2); therefore, CI 9190 probably had increased seed weight in competitive stands. When CI 9184 was the competitor isoline of CI 9191, tillers per plant increased by more than 50%. The increased tillers per plant accounted for sizable increases in numbers of spikelets and primary and secondary florets per plant and ultimately biomass and grain yield. The 45% grain yield advantage for CI 9192 in competitive stands was due to greater numbers of spikelets and primary and secondary florets per plant which resulted from plants with larger panicles. This is further evidence that competitive advantages are related to biomass or grain yield components.

Competitive advantages and disadvantages measured on individual pairs of entries were greatest in Experiment IV. Biomass of Richland decreased and increased 95% in magnitude when grown with Cherokee and M32, respectively, in competitive stands. A significant decrease in tillers (58%) resulted when Cherokee was the competitor of Richland. This was reflected in decreases of 90%, 150%, 148%, and 168% for grain yield and numbers of spikelets and primary and secondary florets, respectively. A 31% increase in tillers per plant when M32 was the competitor of Richland resulted in a 95% increase in biomass. Secondarily, grain yield increased 64% and numbers of spikelets and primary and secondary florets increased 76%, 52%, and 74%, respectively. Thus, all competitive effects of M32 upon Richland more or less emanate from the effect on tillering.

The isolines used in Experiment II were the same ones used by Murphy et al. (1982) to study the compositional stability of an oat multiline. Thus, I am able to compare the competitive ability ratings for these isolines directly with their survival in a multiline. They found CI 9192 was significantly reduced from the mixture, indicating it was a poor competitor, whereas CI 9184 increased in the mixture, indicating it was a good competitor. My results showed that CI 9184 was a poor competitor and CI 9192 was a superior competitor. That is, my ratings of these two isolines for competitive ability and those from Murphy et al. (1982) are diametrical. Several factors may account for the results. First, the studies were conducted in different years. The Murphy study was conducted over a four-year period in the mid to late 1970s and mine was conducted over a two-year period in the early 1980s. The climatic patterns for these periods of years were different and this could have been reflected in different ratings.

Second, and perhaps of more importance, my study was designed to measure competitive ability, whereas the Murphy study measured the ability of isolines to survive a mixture, and these may be different. My study only made use of competition between two genotypes at a time, whereas Murphy et al. (1982) had five competing together. This could have a marked effect on how a given genotype competed with others because the interactions were more complex. Mumaw and Weber (1957), working with variety mixtures of soybeans, illustrated that (a) natural selection can change variety composition very rapidly, (b) the rapidity with which a mixture composition changed was a function of the specific varieties in the mixture, and (c) the changes in varietal frequencies in the early generations of propagation were not necessarily indicative of what varieties would predominate ultimately. Allard and Adams (1969) concluded that competitive relationships described by Schutz and Brim (1967) would have the following effects on bulk populations: (a) the neutral relationship would result in the ultimate fixation of one genotype and, in intermediary generations, some genotypes other than the ones that were ultimately fixed would appear to increase, but ultimately, they would be eliminated; (b) with undercompensation, the genotype with the highest frequency in the initial population would predominate and, with very large numbers of genotypes, establishment of equilibrium would take many generations; (c) complementary interaction would lead to the loss of some components but the persistence of many genotypes; and (d) overcompensation would lead to equilibrium of frequencies of all genotypes and the rapidity of equilibrium of frequencies of all genotypes and the rapidity of equilibrium would depend on the degrees of overcompensation. They concluded that no population would contain only one interaction system, but a mixture or range of systems which would lead to a relatively undefinable situation in a population such as the one grown by Murphy et al. (1982).

Third, Murphy et al. (1982) and I used different experimental designs. They grew bulks, and many different genotypes competed with any one genotype at the same time. In my study, all competitive stands had only two genotypes. The result could be that the interactions in the Murphy study probably were much more complex than those that occurred in mine. Further research needs to be conducted on methods to determine competitive ability of entries in complex mixtures.

SUMMARY

Four experiments were grown in each of two years, 1982 and 1983, to evaluate competitive ability. The materials used to study competitive ability consisted of two sets of oat isolines (early and midseason), a set of oat varieties, and a set with two barley and three oat varieties.

The oat isolines showed some evidence for overcompensation, whereas the oat varieties and oat and barley varieties were neutral with respect to competitive ability. Entries within a set were highly variable with respect to mean competitive reactions, and the effects of competition were even more variable when individual pairs were compared. In the two sets of isolines, a large mean deviation for one entry most often was caused by an exceptionally large competitive advantage or disadvantage that occurred for only one paired comparison. In the set in which barley and oats were grown in competitive stands, the competitive advantage or disadvantage shown by an entry tended to be consistent across all or most competitors.

Competitive advantages or disadvantages displayed by oat and barley genotypes for biomass and grain yield usually could be related to biomass or grain yield components. Increases in biomass and grain yield were reflected in significant increases in numbers of spikelets, primary and secondary florets, and tillers per plant. In the experiment where

midseason isolines were grown, different yield components contributed to competitive advantages in biomass and grain yield in different genotypes. These yield components, seed weight, panicle size, and tillers plant, were related to superior competitive ability. Competitive advantages and disadvantages were greatest in the interspecific comparisons.

The isolines used in Experiment II (i.e., midseason isolines) were the same ones used by Murphy et al. (1982) to study the compositional stability of oat multilines. Thus, competitive ability ratings for these isolines were directly compared with their survival in a multiline. Murphy et al. (1982) found that CI 9192 was a poor competitor and CI 9184 a superior competitor, whereas my results showed that CI 9184 was a poor competitor and CI 9192 a superior competitor. Several factors may account for these results, First, the studies were conducted in different years. Second, my study was designed to measure competitive ability, whereas the Murphy study measured the ability of isolines to survive in a mixture. Finally, Murphy et al. (1982) and I used different experimental designs. The Murphy study was grown in bulks, and many different genotypes competed with any one genotype at the same time, whereas, in my study, all competitive stands had only two genotypes.

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APPENDIX

Table 5. Mean biomass (g/plant) for the entries used in Experiment I when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	Mean
CI 8044						
C	-	3.0	4.5***	4.0	2.9	3.6
P	-	3.5	2.8	4.1	3.8	3.6
CI 9170						
C	4.5	-	4.6	3.8	3.3	4.1
P	4.8	-	4.4	3.7	4.1	4.3
CI 9172						
C	3.5	3.0	-	4.1	4.1*	3.7
P	3.7	4.0	-	3.4	2.6	3.4
CI 9173						
C	3.6	3.8	2.5	-	2.8	3.2
P	3.7	3.9	3.5	-	2.3	3.4
CI 9178						
C	3.9	5.0***	3.3	3.2	-	3.9
P	3.1	2.8	4.1	3.8	-	3.5
Mean						
C	3.9	3.7	3.7	3.8	3.3	3.7
P	3.8	3.6	3.7	3.8	3.2	3.6

*,***Significant at the 10% and 1% levels, respectively.

Table 6. Mean grain yield (g/plant) for the entries used in Experiment I when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	Mean
CI 8044						
C	-	1.5	2.2**	1.9	1.4	1.8
P	-	1.5	1.2	1.7	1.7	1.5
CI 9170						
C	2.2	-	2.2	1.8	1.6	2.0
P	2.2	-	2.0	1.7	2.0	2.0
CI 9172						
C	1.6	1.3	-	2.0	1.6	1.6
P	1.7	1.9	-	1.4	1.3	1.6
CI 9173						
C	1.6	2.0	1.1	-	1.3	1.5
P	1.7	1.9	1.8**	-	1.1	1.6
CI 9178						
C	1.7	1.8	1.4	1.6	-	1.6
P	1.3	1.3	1.6	1.6	-	1.3
Mean						
C	1.8	1.7	1.7	1.8	1.5	1.7
P	1.7	1.7	1.7	1.6	1.5	1.6

**Significant at the 5% level.

Table 7. Mean number of spikelets per plant for the entries used in Experiment I when grown in competitive (C) and pure (P) stands

Entry	Competitor CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	Mean
CI 8044						
C	-	29	46***	38	30	36
P	-	31	27	38	36	33
CI 9170						
C	44	-	44	39	33	40
P	48	-	41	39	42	43
CI 9172						
C	34	30	-	40	36	35
P	38	39	-	32	29	35
CI 9173						
C	31	36	23	-	28	30
P	33	35	34*	-	23	31
CI 9178						
C	38	46**	31	35	-	38
P	27	29	36	32	-	31
Mean						
C	37	35	36	38	32	36
P	37	34	35	35	33	35

*,**,***Significant at the 10%, 5%, and 1% levels, respectively.

Table 8. Mean number of primary florets per plant for the entries used in Experiment I when grown in competitive (C) and pure (P) stands

Entry	Competitor					Mean
	CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	
CI 8044						
C	-	27	43***	35	26	33
P	-	28	23	33	33	29
CI 9170						
C	40	-	39	35	32	37
P	43	-	37	36	39	39
CI 9172						
C	30	28	-	37	32	32
P	35	36	-	28	23	31
CI 9173						
C	28	29	22	-	24	26
P	30	32	32*	-	21	29
CI 9178						
C	29	35	28	30	-	31
P	24	25	26	29	-	26
Mean						
C	32	30	33	34	29	32
P	33	30	30	32	29	31

*,***Significant at the 10% and 1% levels, respectively.

Table 9. Mean number of secondary florets per plant for the entries used in Experiment I when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	Mean
CI 8044						
C	-	26	40***	32	23	30
P	-	27	22	31	31	28
CI 9170						
C	38	-	37	32	29	34
P	38	-	34	32	36	35
CI 9172						
C	27	26	-	32	30	29
P	30	33	-	26	23	28
CI 9173						
C	26	29	19	-	22	24
P	29	30	28*	-	20	27
CI 9178						
C	29*	33	24	28	-	29
P	18	23	26	26	-	23
Mean						
C	30	29	30	31	26	29
P	29	28	28	29	28	28

*,***Significant at the 10% and 1% levels, respectively.

Table 10. Mean number of tillers per plant for the entires used in Experiment I when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	Mean
CI 8044						
C	-	1.6	1.5	1.4	1.7	1.6
P	-	1.4	1.5	1.6	1.7	1.6
CI 9170						
C	1.8	-	1.7	1.6	1.3	1.6
P	1.8	-	1.7	1.8	1.7	1.8
CI 9172						
C	1.5	1.3	-	1.5	1.6	1.5
P	1.6	1.4	-	1.6	1.4	1.5
CI 9173						
C	1.4	1.6	1.2	-	1.4	1.4
P	1.5	1.6	1.5	-	1.3	1.5
CI 9178						
C	1.4	1.9	1.5	1.8	-	1.7
P	1.6	1.8	1.6	1.6	-	1.7
Mean						
C	1.5	1.6	1.5	1.6	1.5	1.6
P	1.6	1.6	1.6	1.7	1.5	1.6

Table 11. Mean heading date for the entries used in Experiment I when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	Mean
CI 8044						
C	-	54	59	59	59	58
P	-	59***	60	58	59	59
CI 9170						
C	58	-	58	60*	60	59
P	59	-	59	58	59	59
CI 9172						
C	60	60	-	59	59	60
P	59	60	-	59	60	60
CI 9173						
C	59	59	59	-	59	59
P	59	59	58	-	59	59
CI 9178						
C	59	58	59	58	-	59
P	59	59	59	60**	-	59
Mean						
C	59	58	59	59	59	59
P	59	59	59	59	59	59

*,**,***Significant at the 10%, 5%, and 1% levels, respectively.

Table 12. Mean height (cm) for the entries used in Experiment I when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 8044	CI 9170	CI 9172	CI 9173	CI 9178	Mean
CI 8044						
C	-	89	101***	92	85	92
P	-	95**	90	96	90	93
CI 9170						
C	98	-	93	97**	95	96
P	92	-	97	88	91	92
CI 9172						
C	92	91	-	92	92	92
P	93	94	-	95	90	93
CI 9173						
C	91	95	84	-	93*	91
P	91	90	91	-	83	89
CI 9178						
C	91	95**	92	92	-	93
P	90	81	91	89	-	88
Mean						
C	93	93	93	93	91	93
P	92	90	92	92	89	91

*,**,***Significant at the 10%, 5%, and 1% levels, respectively.

Table 13. Mean biomass (g/plant) of the entries used in Experiment II when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	Mean
CI 9183						
C	-	3.2	3.1	3.9	3.1	3.3
P	-	3.7	2.8	3.6	3.1	3.3
CI 9184						
C	3.5	-	3.1	3.1	4.1	3.5
P	4.2	-	3.6	3.8	3.2	3.7
CI 9190						
C	2.8	3.1	-	3.7	3.8	3.4
P	2.4	3.6	-	3.0	4.3	3.3
CI 9191						
C	2.9	3.7	3.5	-	3.5	3.4
P	3.3	2.7	3.3	-	2.9	3.1
CI 9192						
C	3.1	5.3**	4.3	3.1	-	4.0
P	3.4	2.4	2.8	2.4	-	2.8
Mean						
C	3.1	3.8	3.5	3.5	3.6	3.5
P	3.3	3.1	3.1	3.2	3.4	3.2

**Significant at the 5% level.

Table 14. Mean grain yield (g/plant) of the entries used in Experiment II when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	Mean
CI 9183						
C	-	1.6	1.4	1.5	1.6	1.5
P	-	1.8	1.4	1.8	1.5	1.6
CI 9184						
C	1.5	-	1.5	1.4	1.8	1.6
P	1.8	-	1.9	1.8	1.7	1.8
CI 9190						
C	2.9***	1.6	-	1.7	1.7	2.0
P	1.2	1.6	-	1.5	2.1	1.6
CI 9191						
C	1.4	2.0	1.5	-	1.7	1.7
P	1.8	1.4	1.5	-	1.4	1.5
CI 9192						
C	1.6	2.4**	2.1	1.4	-	1.9
P	1.5	1.2	1.4	1.1	-	1.3
Mean						
C	1.9	1.9	1.6	1.5	1.7	1.7
P	1.6	1.5	1.6	1.6	1.7	1.6

,*Significant at the 5% and 1% levels, respectively.

Table 15. Mean number of spikelets per plant for the entries used in Experiment II when grown in competitive (C) and pure (P) stands

Entry	Competitor					Mean
	CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	
CI 9183						
C	-	42	45	50	44	45
P	-	49	39	46	50	46
CI 9184						
C	43	-	45	41	48	44
P	55	-	47	47	44	48
CI 9190						
C	40	43	-	48	47	45
P	36	45	-	39	53	43
CI 9191						
C	39	50	40	-	45	44
P	47	34	40	-	40	40
CI 9192						
C	44	62	57	41	-	51
P	47	40	43	35	-	41
Mean						
C	42	49	47	45	46	46
P	46	42	42	42	47	44

Table 16. Mean number of primary florets per plant for the entries used in Experiment II when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	Mean
CI 9183						
C	-	36	40	41	38	39
P	-	43	35	43	48	42
CI 9184						
C	37	-	42	39	42	40
P	47	-	40	42	39	42
CI 9190						
C	36	37	-	41	40	39
P	31	38	-	37	49	39
CI 9191						
C	34	46	36	-	40	39
P	44	30	35	-	35	36
CI 9192						
C	41	57	53	39	-	48
P	41	35	39	32	-	37
Mean						
C	37	44	43	40	40	41
P	41	37	37	39	43	39

Table 17. Mean number of secondary florets per plant for the entries used in Experiment II when grown in competitive (C) and pure (P) stands

Entry	Competitor					Mean
	CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	
CI 9183						
C	-	30	30	33	29	31
P	-	39	27	29	39	34
CI 9184						
C	33	-	34	30	36	33
P	41	-	37	34	35	37
CI 9190						
C	30	30	-	34	30	31
P	24	29	-	30	42**	31
CI 9191						
C	27	42	30	-	34	33
P	37	25	27	-	29	30
CI 9192						
C	34	50**	43	27	-	39
P	30	24	32	24	-	28
Mean						
C	31	38	34	31	32	33
P	33	29	31	29	36	32

**Significant at the 5% level.

Table 18. Mean number of tillers per plant for the entries used in Experiment II when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	Mean
CI 9183						
C	-	1.5	1.6	2.0	1.4	1.6
P	-	1.6	1.5	1.8	1.7	1.7
CI 9184						
C	1.5	-	1.7	1.9	1.8	1.7
P	1.6	-	1.6	1.6	1.5	1.6
CI 9190						
C	1.3	1.5	-	1.8	1.5	1.5
P	1.6	1.5	-	1.4	1.5	1.5
CI 9191						
C	1.3	1.9**	1.5	-	1.3	1.5
P	1.5	1.2	1.5	-	1.3	1.4
CI 9192						
C	1.5	1.6	1.8	1.5	-	1.6
P	1.9	1.8	1.4	1.2	-	1.6
Mean						
C	1.4	1.6	1.7	1.8	1.5	1.6
P	1.7	1.5	1.5	1.5	1.5	1.6

**Significant at the 5% level.

Table 19. Mean heading date for the entries used in Experiment II when grown in competitive (C) and pure (P) stands

Entry	Competitor					Mean
	CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	
CI 9183						
C	-	66	67	66	66	66
P	-	66	67	66	66	66
CI 9184						
C	66	-	65	66	65	66
P	65	-	66	65	65	65
CI 9190						
C	66	64	-	66	67	66
P	66	66**	-	66	66	66
CI 9191						
C	65	64	66	-	66	65
P	66	65	65	-	66	66
CI 9192						
C	66	65	66	65	-	66
P	66	66	66	68***	-	67
Mean						
C	66	65	66	66	66	66
P	66	66	66	66	66	66

,*Significant at the 5% and 1% levels, respectively.

Table 20. Mean height (cm) for the entries used in Experiment II when grown in competitive (C) and pure (P) stands

Entry	Competitor CI 9183	CI 9184	CI 9190	CI 9191	CI 9192	Mean
CI 9183						
C	-	96	100	103	95	99
P	-	105	103	97	92	99
CI 9184						
C	97	-	96	95	102*	98
P	101	-	93	96	91	95
CI 9190						
C	89	92	-	91	106	95
P	97	90	-	95	100	96
CI 9191						
C	98	96	100	-	98	98
P	93	99	93	-	101	97
CI 9192						
C	96	104	99	87	-	97
P	104	93	96	101*	-	99
Mean						
C	95	97	99	94	100	97
P	99	97	96	97	96	97

*Significant at the 10% level.

Table 21. Mean biomass (g/plant) for the entries used in Experiment III when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Benson	Chief	Garland	Noble	Ogle	Mean
Benson						
C	-	3.3	3.6	2.8	3.0	3.2
P	-	3.7	3.3	2.2	3.7	3.2
Chief						
C	2.4	-	2.9	2.8	2.9	2.8
P	2.6	-	3.2	2.5	2.7	2.8
Garland						
C	2.7	2.8	-	2.2	3.7	2.9
P	3.2	3.1	-	3.4*	3.3	3.3
Noble						
C	3.4	2.6	3.0	-	2.8	3.0
P	2.6	2.7	3.5	-	2.4	2.8
Ogle						
C	2.2	3.1	4.0	3.5	-	3.2
P	1.9	3.2	3.6	3.0	-	2.9
Mean						
C	2.7	3.0	3.4	2.8	3.1	3.0
P	2.6	3.2	3.4	2.8	3.0	3.0

*Significant at the 10% level.

Table 22. Mean grain yield (g/plant) for the entries used in Experiment III when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Benson	Chief	Garland	Noble	Ogle	Mean
Benson						
C	-	1.5	2.1	1.3	1.3	1.6
P	-	1.8	1.6	1.1	1.9	1.5
Chief						
C	1.1	-	1.4	1.4	1.3	1.3
P	1.4	-	1.6	1.3	1.4	1.4
Garland						
C	1.3	1.4	-	1.1	1.8	1.4
P	1.5	1.4	-	1.7	1.4	1.5
Noble						
C	1.6	1.2	1.4	-	1.4	1.4
P	1.3	1.3	1.6	-	1.3	1.4
Ogle						
C	1.1	1.6	2.0	1.8	-	1.6
P	1.3	1.6	1.6	1.4	-	1.6
Mean						
C	1.3	1.4	1.7	1.4	1.5	1.5
P	1.4	1.5	1.6	1.4	1.5	1.5

Table 23. Mean number of spikelets per plant for the entries used in Experiment III when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Benson	Chief	Garland	Noble	Ogle	Mean
Benson						
C	-	44	45	31	36	39
P	-	34	33	25	44	34
Chief						
C	30	-	37	39	36	36
P	37	-	39	33	34	36
Garland						
C	29	34	-	30	48	35
P	43	35	-	40	38	39
Noble						
C	37	29	37	-	33	34
P	37	35	37	-	29	35
Ogle						
C	27	34	46	37	-	36
P	31	34	35	36	-	34
Mean						
C	31	35	41	34	38	36
P	37	35	36	34	36	36

Table 24. Mean number of primary florets per plant for the entries used in Experiment III when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Benson	Chief	Garland	Noble	Ogle	Mean
Benson						
C	-	31	39	23	31	31
P	-	32	29	21	31	28
Chief						
C	26	-	31	34	30	30
P	32	-	31	30	30	31
Garland						
C	24	30	-	26	43	31
P	35	30	-	34	30	32
Noble						
C	28	25	30	-	28	28
P	29	27	32	-	24	28
Ogle						
C	24	30	42*	34	-	33
P	26	28	30	31	-	29
Mean						
C	26	29	36	29	33	31
P	31	29	31	29	29	30

*Significant at the 10% level.

Table 25. Mean number of secondary florets per plant for the entries used in Experiment III when grown in competitive (C) and pure (P) stands

Entry	Competitor					Mean
	Benson	Chief	Garland	Noble	Ogle	
Benson						
C	-	29	33	20	21	26
P	-	31	26	19	29	26
Chief						
C	22	-	24	26	26	25
P	27	-	26	25	26	26
Garland						
C	21	25	-	22	33	25
P	27	25	-	29	26	27
Noble						
C	24	20	26	-	23	23
P	25	23	26	-	20	24
Ogle						
C	18	22	35**	28	-	26
P	21	22	24	24	-	23
Mean						
C	21	24	30	24	26	25
P	25	25	26	24	25	25

**Significant at the 5% level.

Table 26. Mean number of tillers per plant for the entries used in Experiment III when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Benson	Chief	Garland	Noble	Ogle	Mean
Benson						
C	-	1.6	1.5	1.5	1.4	1.5
P	-	1.4	1.2	1.2	1.4	1.3
Chief						
C	1.2	-	1.4	1.3	1.4	1.3
P	1.6	-	1.6	1.1	1.3	1.4
Garland						
C	1.4	1.3	-	1.1	1.6	1.4
P	1.2	1.6	-	1.7**	1.4	1.5
Noble						
C	1.5	1.4	1.6	-	1.5	1.5
P	1.4	1.3	1.6	-	1.4	1.4
Ogle						
C	1.2	1.3	1.6	1.3	-	1.4
P	1.5	1.1	1.2	1.3	-	1.3
Mean						
C	1.3	1.4	1.5	1.3	1.5	1.4
P	1.4	1.4	1.4	1.3	1.4	1.4

**Significant at the 5% level.

Table 27. Mean heading date for the entries used in Experiment III when grown in competitive (C) and pure P) stands

Entry	Competitor					Mean
	Benson	Chief	Garland	Noble	Ogle	
Benson						
C	-	69	66	70	69	69
P	-	69	69***	70	70	70
Chief						
C	68	-	67	68	68	68
P	68	-	68	68	67	68
Garland						
C	69**	66	-	65	67	67
P	66	65	-	66	66	66
Noble						
C	69***	68	67	-	67	68
P	66	68	67	-	68	67
Ogle						
C	69	68	67	67	-	68
P	68	68	67	67	-	68
Mean						
C	69	68	67	68	68	68
P	67	68	68	68	68	68

,*Significant at the 5% and 1% levels, respectively.

Table 28. Mean height (cm) for the entries used in Experiment III when grown in competitive (C) and pure (P) stands

Entry	Competitor: Benson	Chief	Garland	Noble	Ogle	Mean
Benson						
C	-	84	95	85	94	90
P	-	88	87	95	95	91
Chief						
C	85	-	85	94	96	90
P	83	-	98	86	92	90
Garland						
C	86	93	-	86	88	88
P	91	81	-	83	87	86
Noble						
C	97	90	88	-	88	91
P	90	91	85	-	80	87
Ogle						
C	89	97	93	96	-	94
P	91	90	93	86	-	90
Mean						
C	89	91	90	90	92	91
P	89	88	91	88	89	89

Table 29. Mean biomass (g/plant) for the entries used in Experiment IV when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Cherokee	CI 9268	M32	Richland	W38	Mean
Cherokee						
C	-	3.6	2.7	2.7	3.1	3.0
P	-	3.0	4.7**	3.2	2.5	3.4
CI 9268						
C	4.4*	-	3.3	2.4	3.1	3.3
P	2.7	-	2.4	3.3	2.5	2.7
M32						
C	4.3**	3.1	-	3.5	3.2	3.5
P	2.6	2.9	-	3.2	2.6	2.8
Richland						
C	1.9	3.7	3.7*	-	3.2	3.1
P	3.7***	2.5	1.9	-	2.7	2.7
W38						
C	3.6	5.2	3.1	3.1	-	3.8
P	5.2**	3.6	3.6	6.5**	-	4.7
Mean						
C	3.6	3.9	3.2	2.9	3.2	3.3
P	3.6	3.0	3.2	4.1	2.5	3.3

*,**,***Significant at the 10%, 5%, and 1% levels, respectively.

Table 30. Mean grain yield (g/plant) for the entries used in Experiment IV when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Cherokee	CI 9268	M32	Richland	W38	Mean
Cherokee						
C	-	1.9	1.5	1.5	1.5	1.6
P	-	1.5	2.1	1.5	1.3	1.6
CI 9268						
C	2.0	-	1.8	1.3	1.7	1.7
P	1.2	-	1.2	1.7	1.2	1.3
M32						
C	2.0	1.8	-	1.8	1.7	1.8
P	1.5	1.6	-	1.7	1.6	1.6
Richland						
C	1.0	1.9	1.8	-	0.9	1.4
P	1.9**	1.1	1.1	-	1.4	1.4
W38						
C	1.8	2.2	1.6	1.4	-	1.8
P	3.0***	1.5	1.8	2.9**	-	2.3
Mean						
C	1.7	2.0	1.7	1.5	1.5	1.7
P	1.9	1.4	1.6	2.0	1.4	1.6

,*Significant at the 5% and 1% levels, respectively.

Table 31. Mean number of spikelets per plant for the entries used in Experiment IV when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Cherokee	CI 9268	M32	Richland	W38	Mean
Cherokee						
C	-	40	32	30	31	33
P	-	34	46*	31	26	34
CI 9268						
C	48*	-	42*	29	35	39
P	31	-	25	35	28	30
M32						
C	32	34**	-	31	34	33
P	31	21	-	28	26	27
Richland						
C	24	41	51*	-	37	38
P	60***	35	29	-	40	41
W38						
C	34	37	31	29	-	33
P	40	35	33	50***	-	40
Mean						
C	35	38	39	30	34	35
P	41	31	33	36	30	34

*,**,***Significant at the 10%, 5%, and 1% levels, respectively.

Table 32. Mean number of primary florets per plant for the oat entries used in Experiment IV when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Cherokee	CI 9268	M32	Richland	W38	Mean
Cherokee						
C	-	36	29	27	29	30
P	-	33	43**	30	25	33
CI 9268						
C	45*	-	34*	26	33	35
P	28	-	22	33	24	27
Richland						
C	21	42	41*	-	34	35
P	52**	34	27	-	36	37
Mean						
C	33	39	35	27	32	33
P	40	34	31	32	29	33

*,**Significant at the 10% and 5% levels, respectively.

Table 33. Mean number of secondary florets per plant for the oat entries used in Experiment IV when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Cherokee	CI 9268	M32	Richland	W38	Mean
Cherokee						
C	-	33	27	25	28	28
P	-	29	37	27	22	29
CI 9268						
C	37*	-	28	22	26	28
P	23	-	19	31	19	23
Richland						
C	19	41	40*	-	28	32
P	51***	30	23	-	31	34
Mean						
C	28	37	32	24	27	30
P	37	30	26	29	24	29

*,***Significant at the 10% and 1% levels, respectively.

Table 34. Mean number of tillers per plant for the entries used in Experiment IV when grown in competitive (C) and pure (P) stands

	Competitor					
Entry	Cherokee	CI 9268	M32	Richland	W38	Mean
Cherokee						
C	-	1.8	1.5	1.4	1.5	1.6
P	-	1.6	2.1*	1.4	1.7	1.7
CI 9268						
C	2.0	-	1.8*	1.5	1.7	1.8
P	1.6	-	1.2	1.6	1.5	1.5
M32						
C	2.1	1.7	-	1.9**	2.0**	1.9
P	1.5	1.3	-	1.3	1.3	1.4
Richland						
C	1.2	1.7	1.7	-	1.2	1.5
P	1.9***	1.3	1.3	-	1.8	1.6
W38						
C	1.6	1.8	1.7	1.7	-	1.7
P	1.7	2.3	1.6	2.4**	-	2.0
Mean						
C	1.7	1.8	1.7	1.6	1.6	1.7
P	1.7	1.6	1.6	1.7	1.6	1.6

*,**,***Significant at the 10%, 5%, and 1% levels, respectively.

Table 35. Mean heading date for the entries used in Experiment IV when grown in competitive (C) and pure (P) stands

Entry	Competitor: Cherokee	CI 9268	M32	Richland	W38	Mean
Cherokee						
C	-	65	64	65	63	64
P	-	64	67	63	65	65
CI 9268						
C	66	-	66	67	69	67
P	68	-	68	67	66	67
M32						
C	61	59	-	62	62	61
P	61	63***	-	61	63	62
Richland						
C	65	66	65	-	64	65
P	66	64	65	-	65	65
W38						
C	65	67	63	67	-	66
P	66	71***	66	65	-	67
Mean						
C	64	64	65	65	65	65
P	65	66	67	64	65	65

***Significant at the 1% level.

Table 36. Mean height (cm) for the entries used in Experiment IV when grown in competitive (C) and pure (P) stands

Entry	Competitor					Mean
	Cherokee	CI 9268	M32	Richland	W38	
Cherokee						
C	-	85	81	86	84	84
P	-	88	98**	88	85	90
CI 9268						
C	95	-	83	85	75	85
P	85	-	80	84	84	83
M32						
C	76***	68	-	70	58	68
P	59	63	-	63	66	63
Richland						
C	91	91	92**	-	80	89
P	85	89	77	-	91	86
W38						
C	87	84	73	81	-	81
P	81	78	75	87	-	80
Mean						
C	87	82	82	81	74	81
P	78	80	83	81	82	80

,*Significant at the 5% and 1% levels, respectively.